Improvements in an ice cloud optical property model
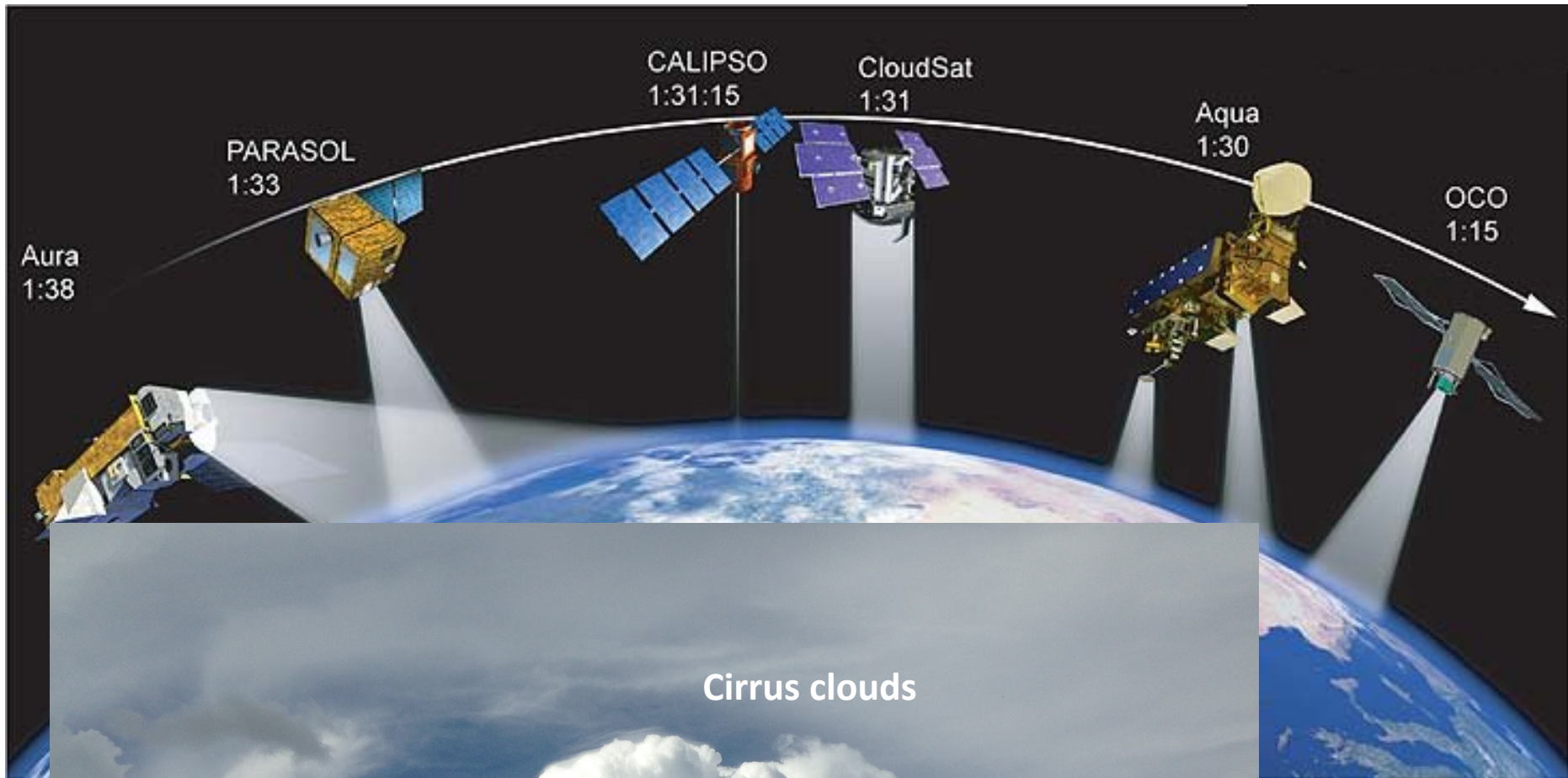
P. Yang, J. Coy, M. Saito, Y. Wang, and J. Ding

Adam Bell (Presenting author)

Texas A&M University

Satellite Observations of Ice clouds
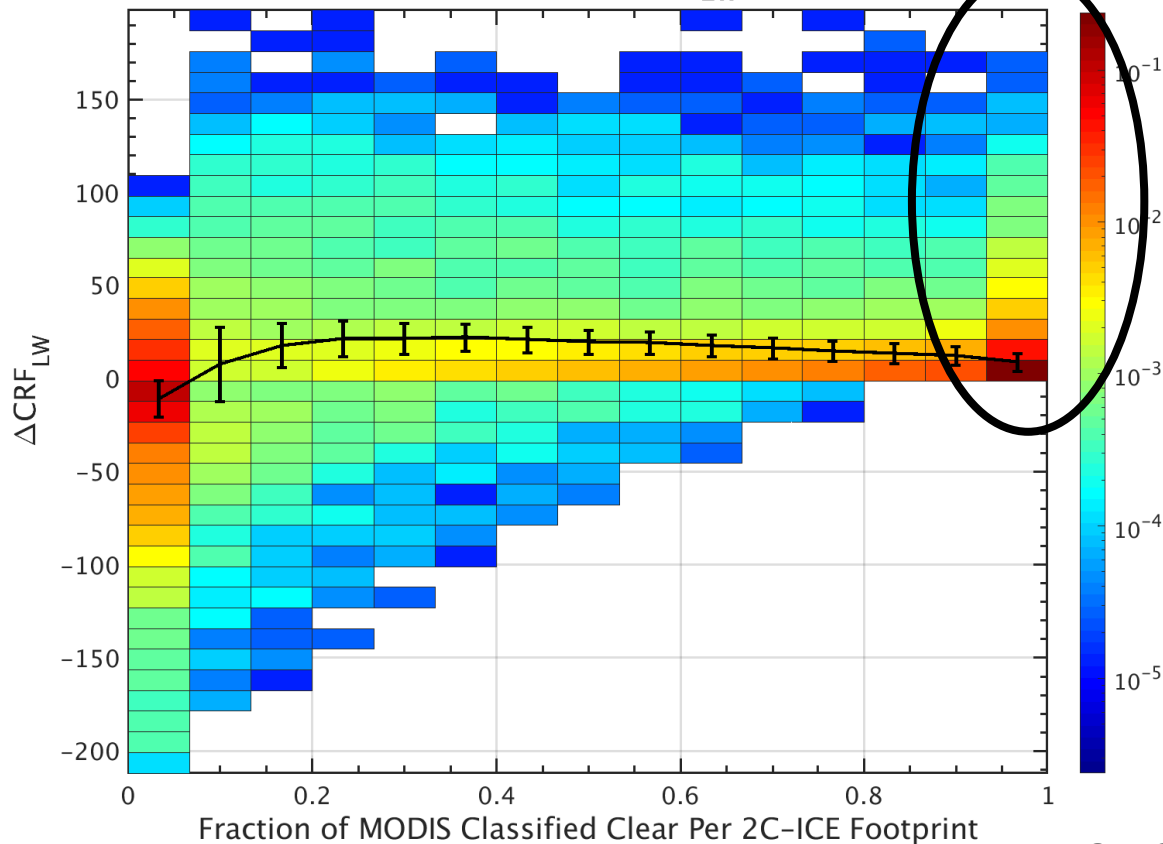

A-Train satellite constellation

Background

Frequency of Contradictions between 2C–ICE and MODIS C6 vs. Resulting ΔCRF_{LW}

Courtesy of Jeffrey C. Mast
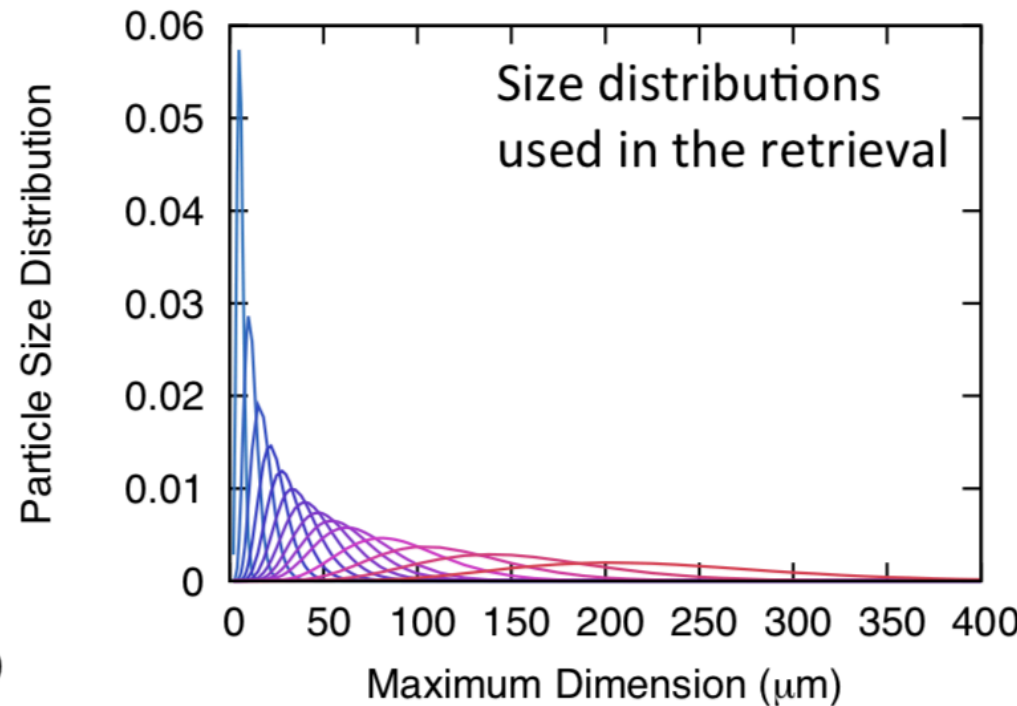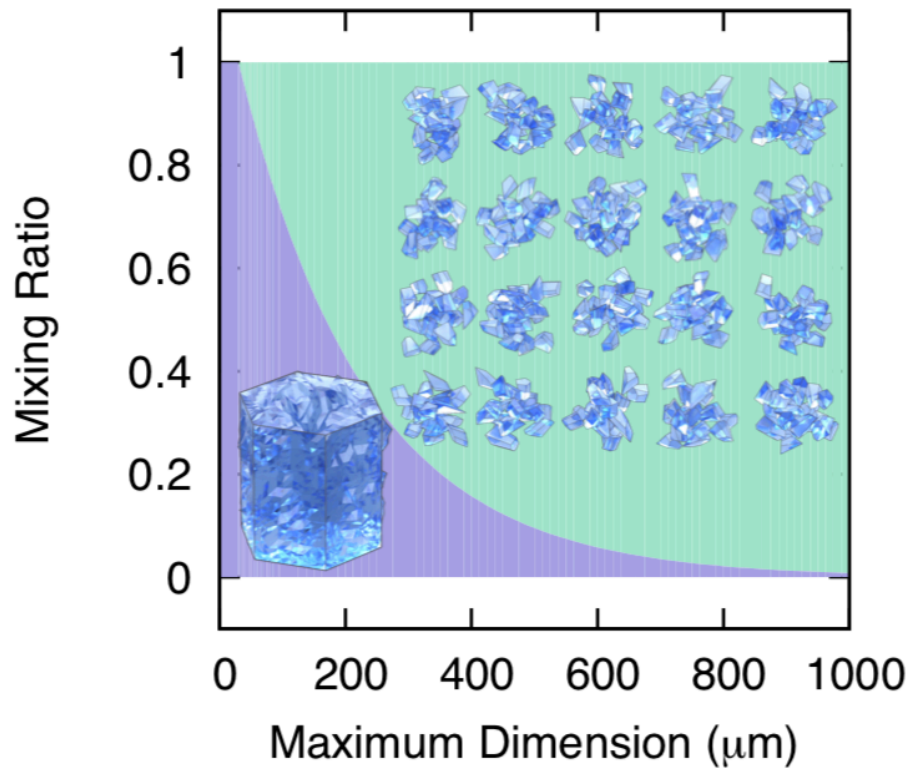
MODIS classifies as clear-sky pixels but Cloudsat–CALIPSO identifies ice clouds.

- Optically thin cirrus clouds play an important role in cloud radiative forcing.
- Cloud optical thickness is retrieved based on an empirical parameterization using lidar backscattering measurements.
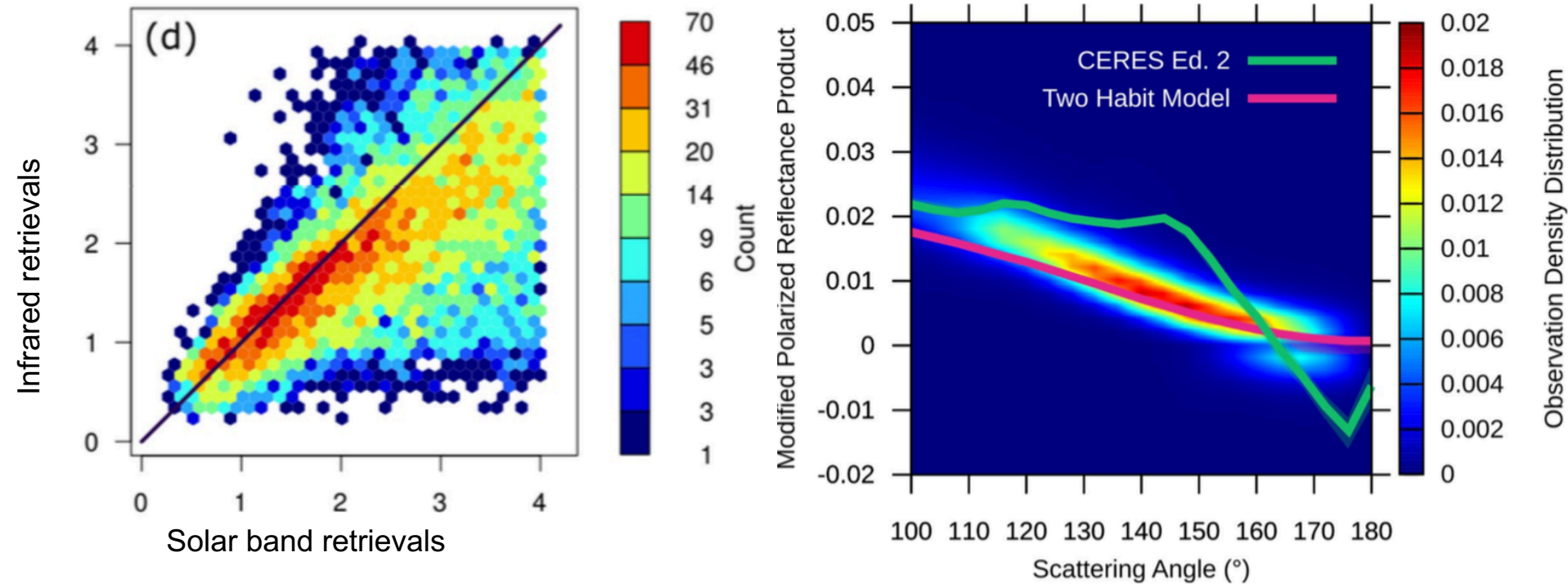
Current Two Habit Model

Hioki et al., 2016 CERES Science Team Meeting

- Current THM (Loeb et al., 2018; Yang et al., 2018)
- Computational methods: II-TM and IGOM
- Spectral & microphysical consistency
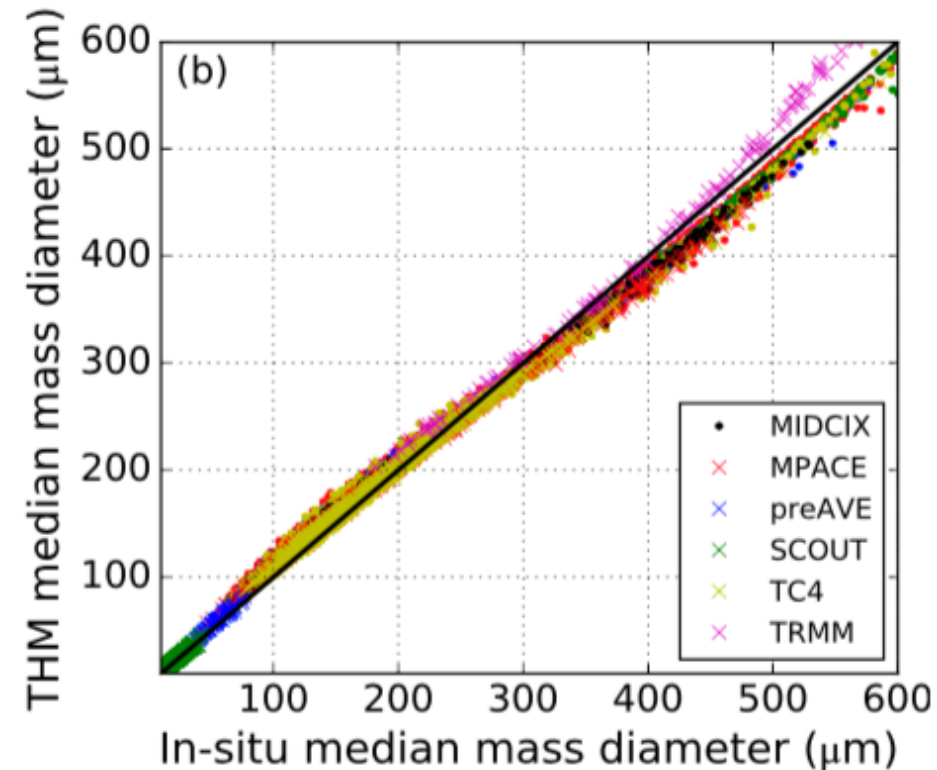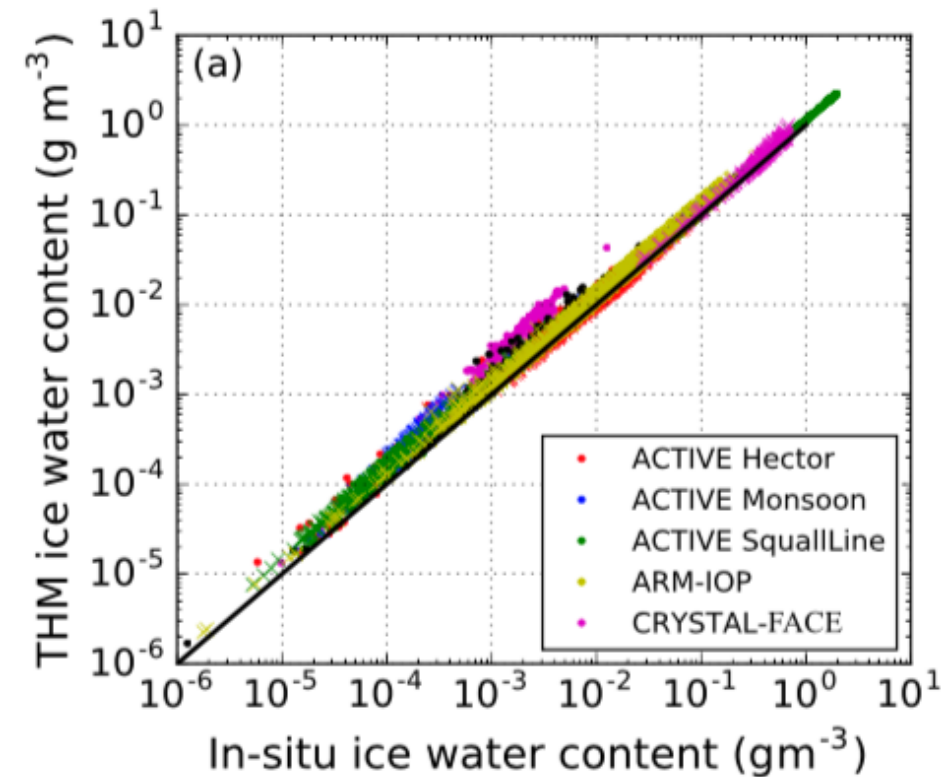
Current THM: Spectral consistency

Cloud optical thickness at 0.55 μm

Yang et al., 2018 Atmosphere

- Ice cloud property retrievals: VIS–NIR vs TIR

- Polarized reflectivity: Simulations vs Observations

- Current THM achieves both consistencies (Yang et al., 2018)
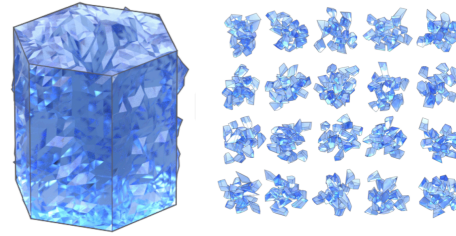
Current THM: Microphysical consistency

Loeb et al., 2018 JClim

- Microphysical consistency between in-situ measurements and current THM counterparts (Loeb et al., 2018)
  1. Ice water content (IWC)
  2. Mass diameter

What is the Future THM?

Loeb, Yang et al., 2018 JClim

Consistency Achieved

- Spectral consistency
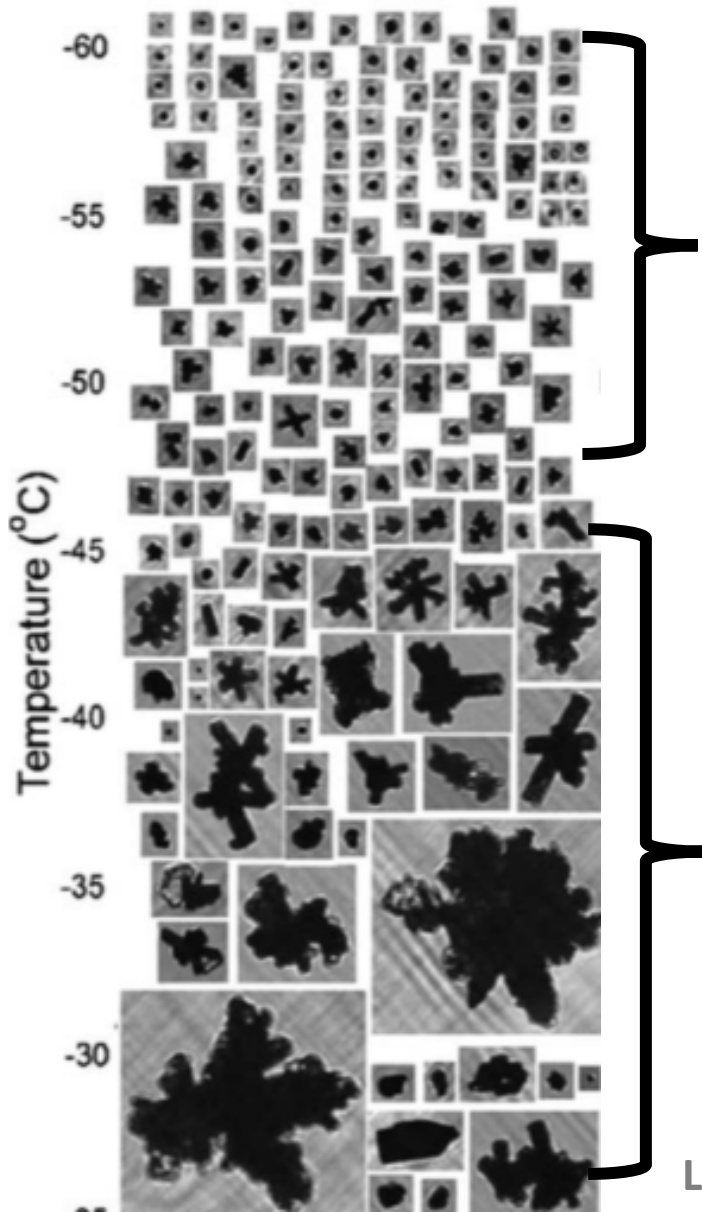
- Polarized reflectance

- Microphysical consistency

This project

Issues in Current THM
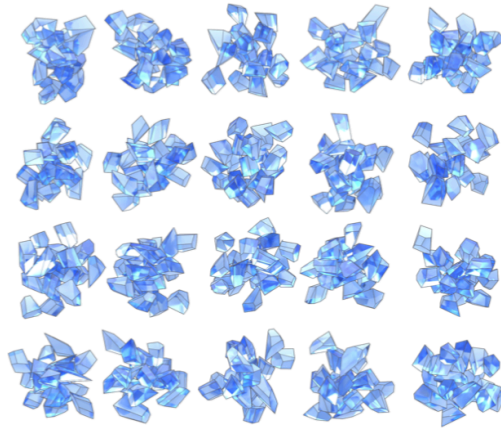
Consistency in Ice Particle Shape

Consistent?

- Variety of shapes
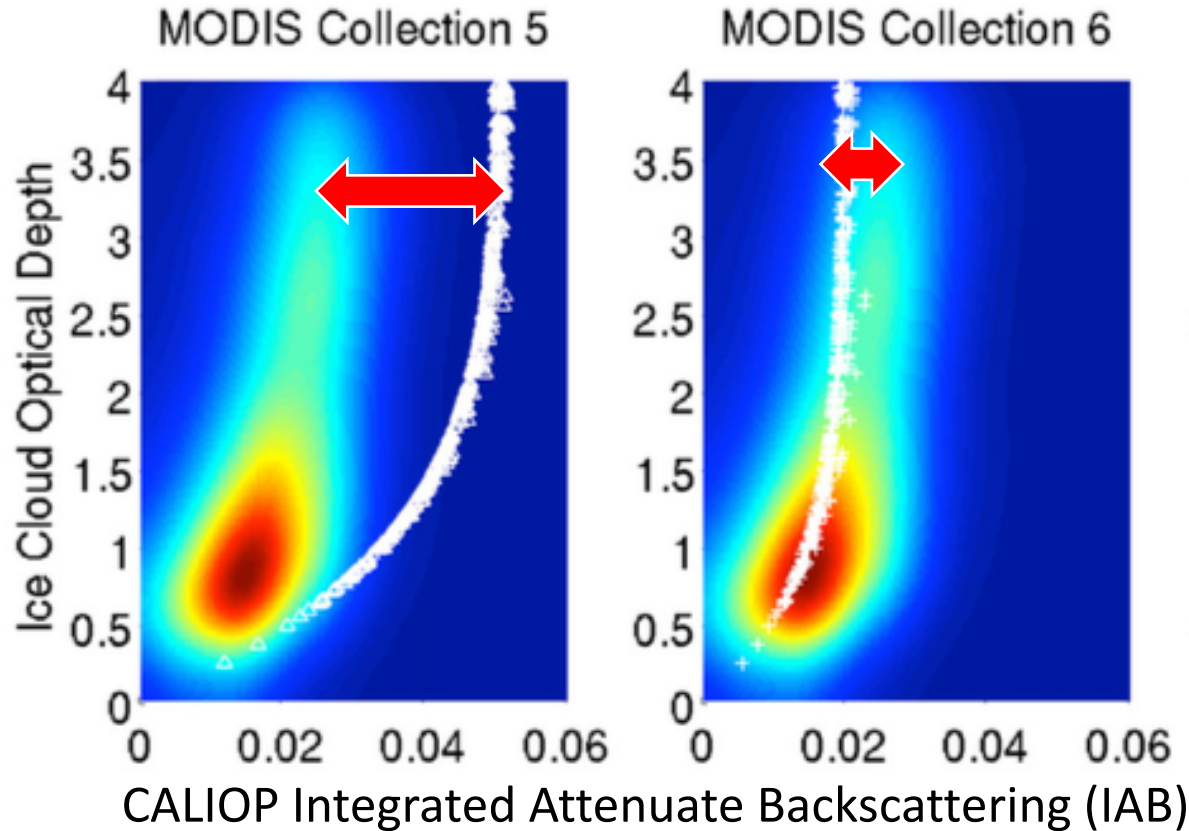- Irregular shapes

→ Single roughened hexagonal column may not work.

Consistent!

Lawson, 2006 JAS

Issues in Current THM

Active and Passive Retrieval Consistency

MODIS Collection 5 | MODIS Collection 6

CALIOP Integrated Attenuate Backscattering (IAB)

Ding, Yang et al., 2016 OE

- Backscattering is not accurate due to inherent limitation in IGOM calculations (biased by 30–200%).

- Poor consistency in active- and passive-based retrievals.

Objectives

- To improve THM with a focus on:
  1. Backscattering property computation
  2. Ice particle shape characterization

Future THM
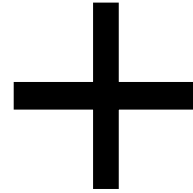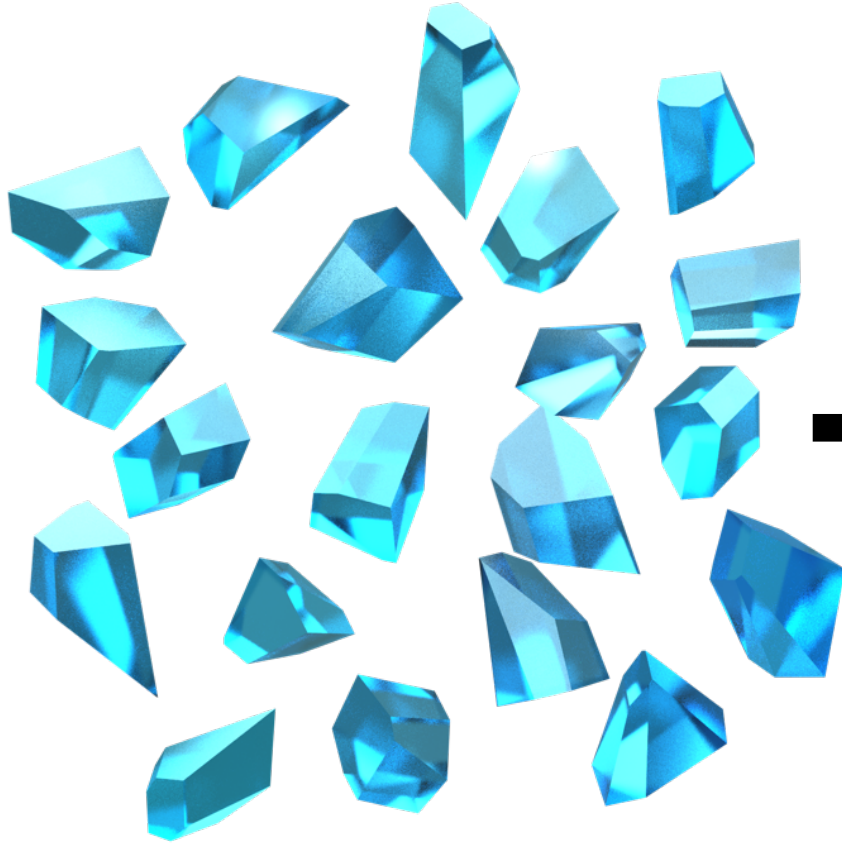
???

will achieve…

Optical Consistency

- Spectral consistency

- Polarized reflectance

- **Active–passive consistency**
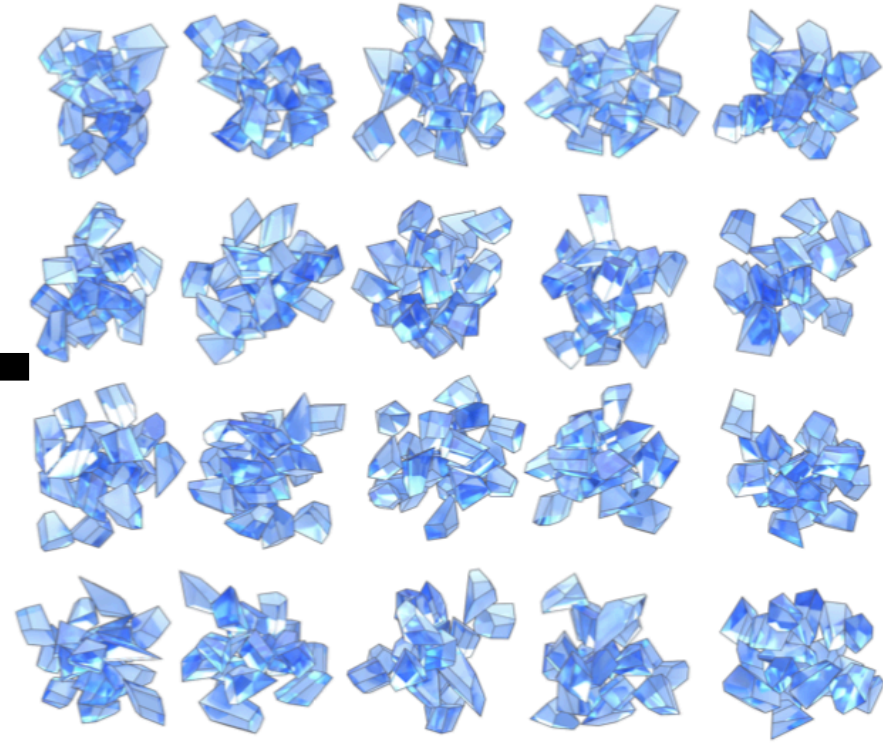
Microphysical Consistency

- Mass diameter & ice water content

- **Ice particle shape**

Future THM

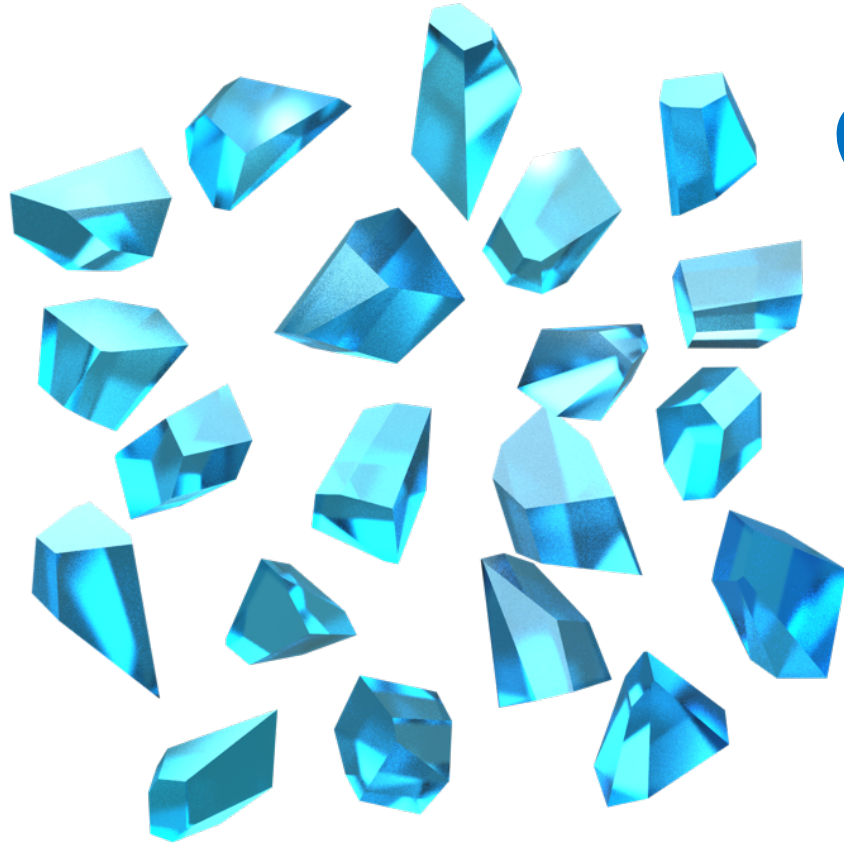**20 irregular hexagonal columns**   20 irregular column aggregates
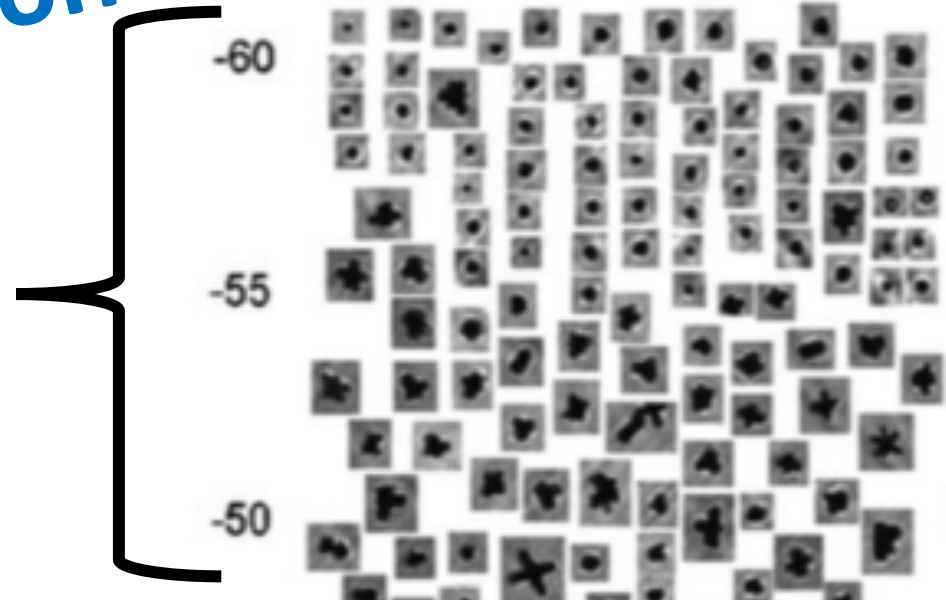

- The single roughened hexagonal column is replaced with ensemble of 20 irregular hexagonal columns.

- The irregularity mimics surface roughness and shape variations of ice crystals.

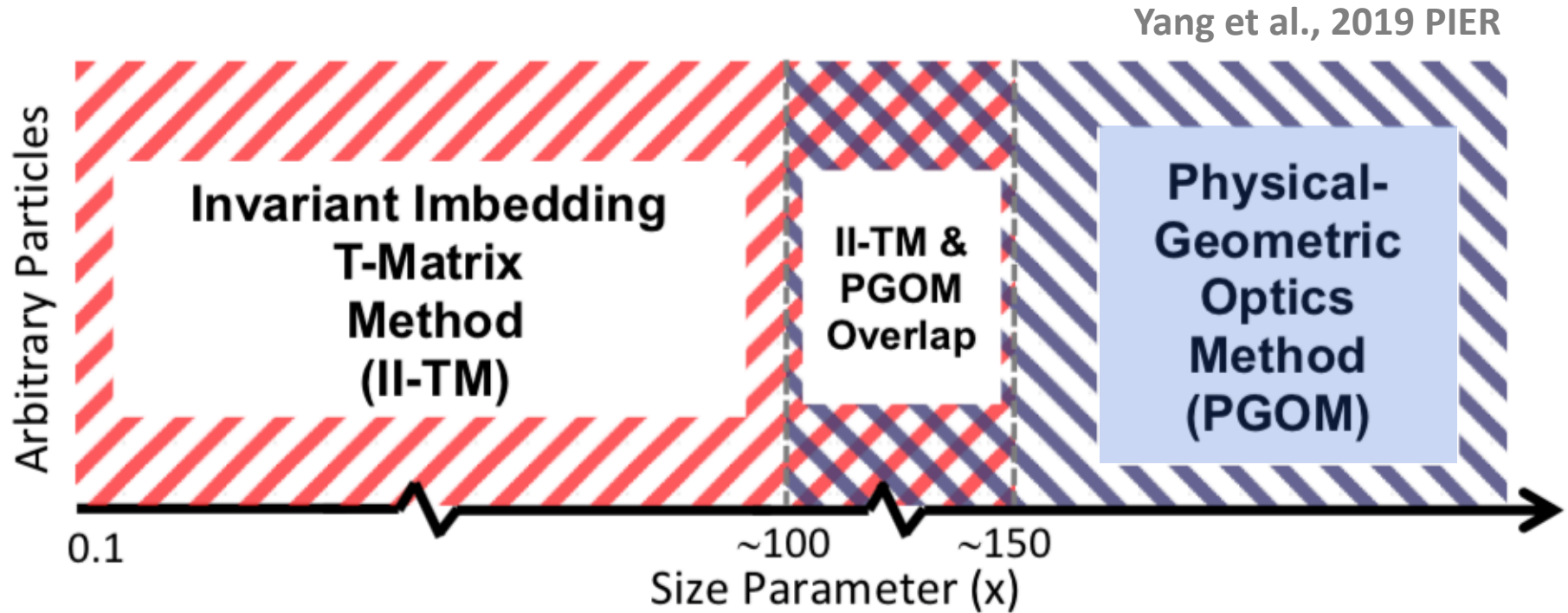# Future THM

20 irregular hexagonal columns

Consistent!

Lawson, 2006 JAS
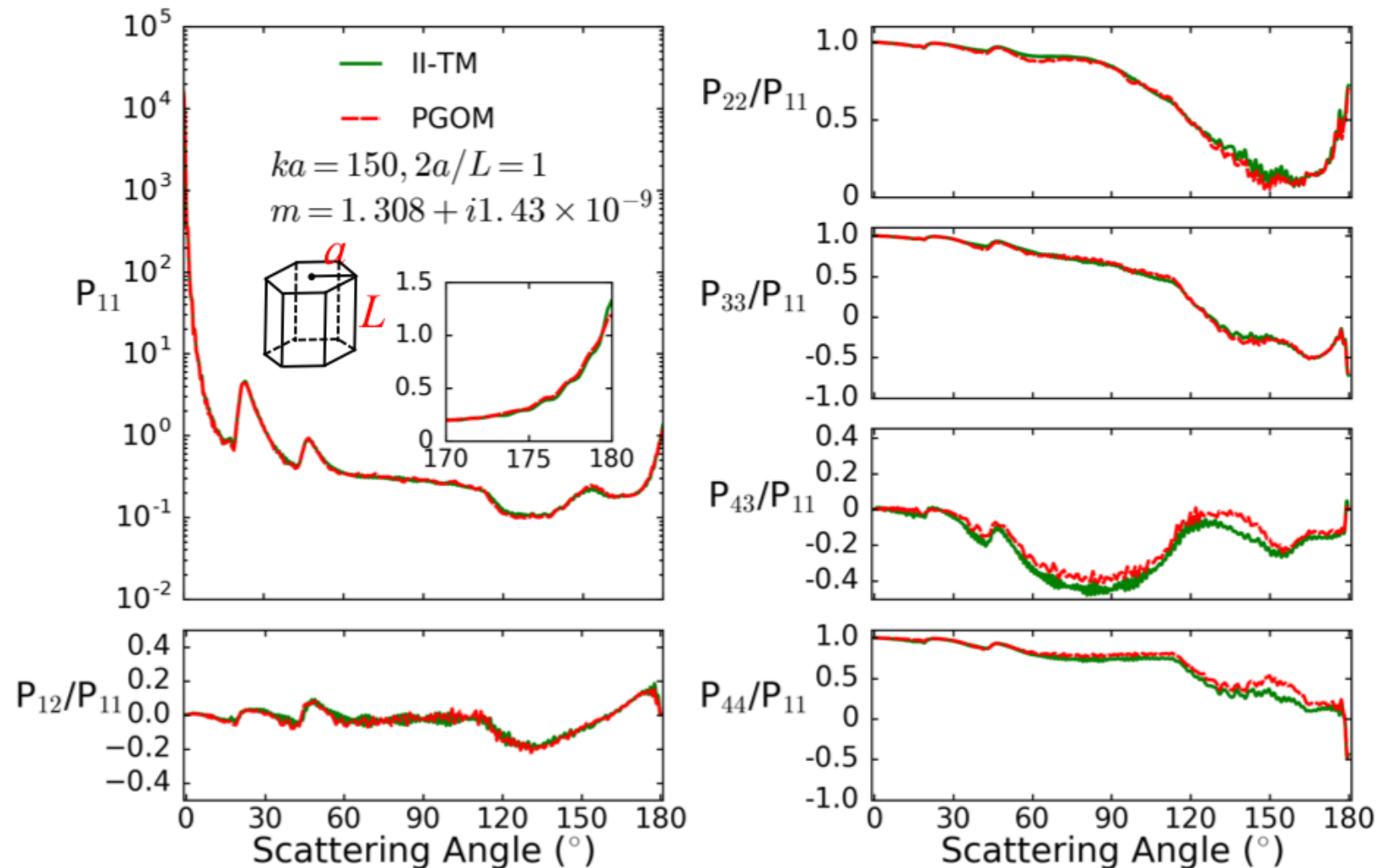
- Consistent with in-situ measured particle shapes for small ice crystals

Light Scattering Computational Capabilities

Yang et al., 2019 PIER

- PGOM (approximated method) achieves consistency in light scattering computations with a numerically exact II-TM.
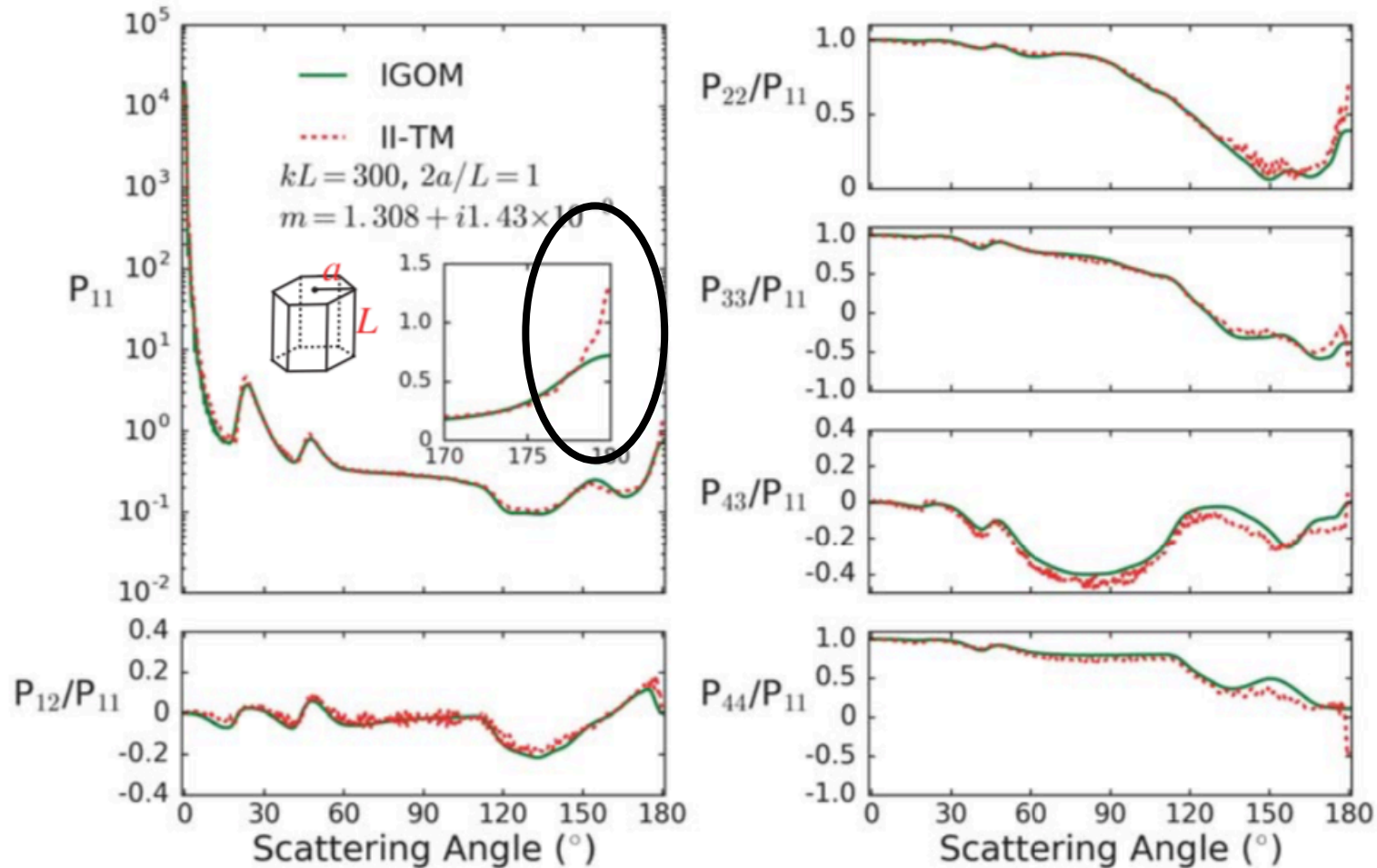
- This talk focuses on PGOM calculations.

Physical Geometric Optics Method
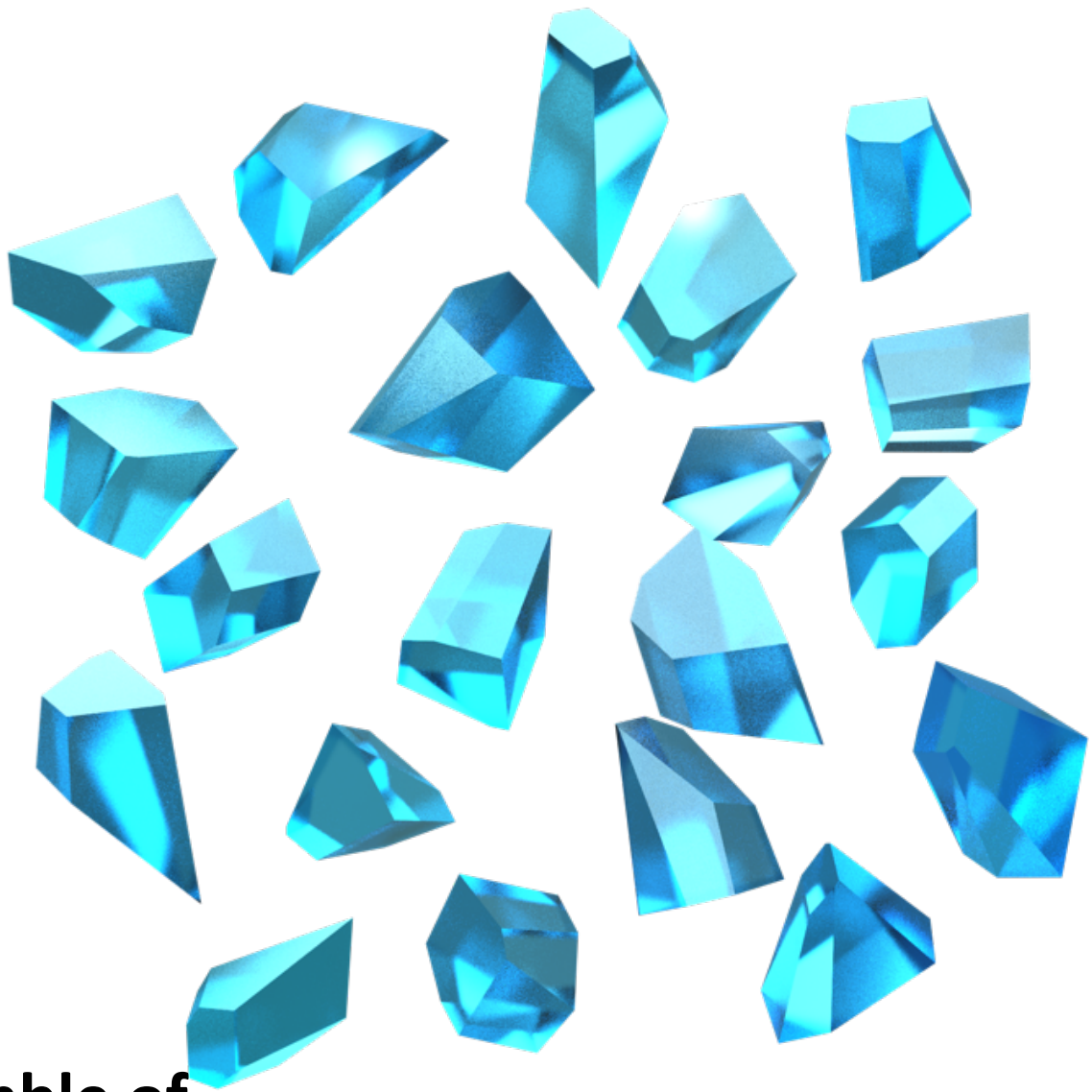

Yang et al., 2019 PIER

- Consistent phase functions at backscattering direction between II-TM and PGOM

Combination of IGOM + PGOM

- PGOM is computationally expensive.

- IGOM is consistent with IITM in forward-to-side scattering angles.

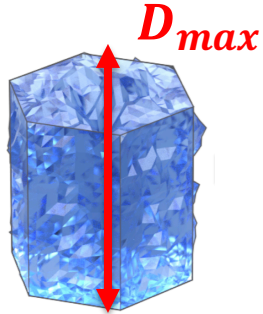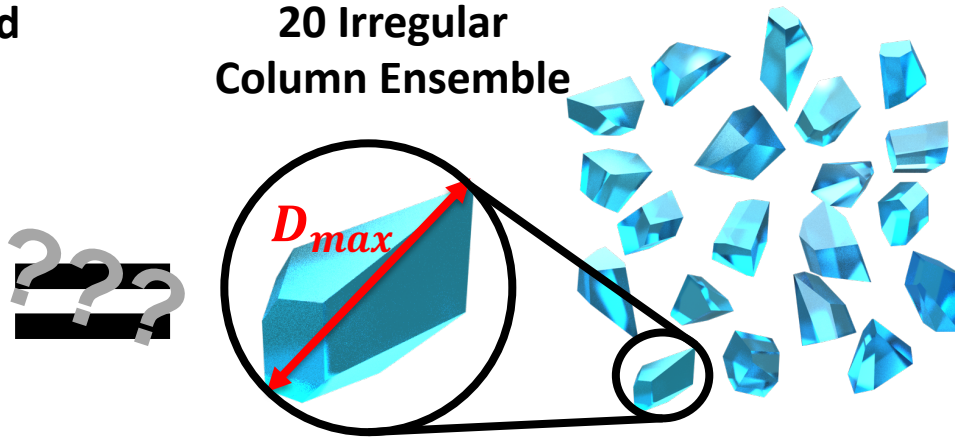→ Combine IGOM (forward-to-side scat.) and PGOM (backscat.)

Results

Focusing on the ensemble of

**20 irregular hexagonal columns
with IGOM + PGOM computations**

Replacing Roughened Single-Column Particles

Single Roughened Column

D_{max}

20 Irregular Column Ensemble

D_{max}

???

Effective Diameter

$$V_{Rough}(D_{max}) \neq V_{Irr}(D_{max})$$

$$A_{p,Rough}(D_{max}) \neq A_{p,Irr}(D_{max})$$

$$D_{eff} = \frac{3V}{2A_p}$$

Volume-equivalent Diameter	Surface Area-equivalent Diameter	Volume/Surface-equivalent Diameter
$$D_{vol} = \left(\frac{6}{\pi}V\right)^{1/3}$$	$$D_{sur} = \left(\frac{1}{\pi}A_{tot}\right)^{1/2}$$	$$D_{VA} = 6\frac{V}{A_{tot}}$$

- Reconsider size characterization instead of Maximum Dimension (D_{max}) to achieve the optical consistency.

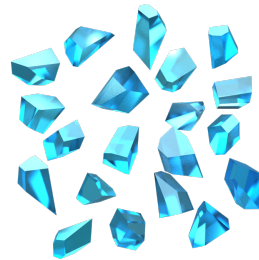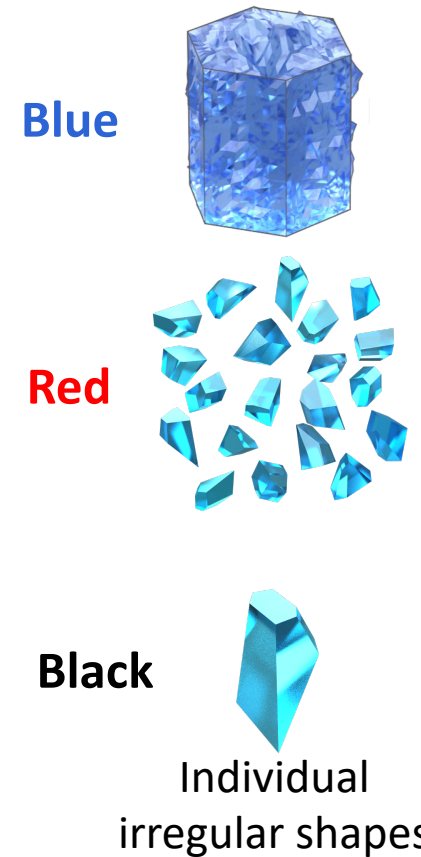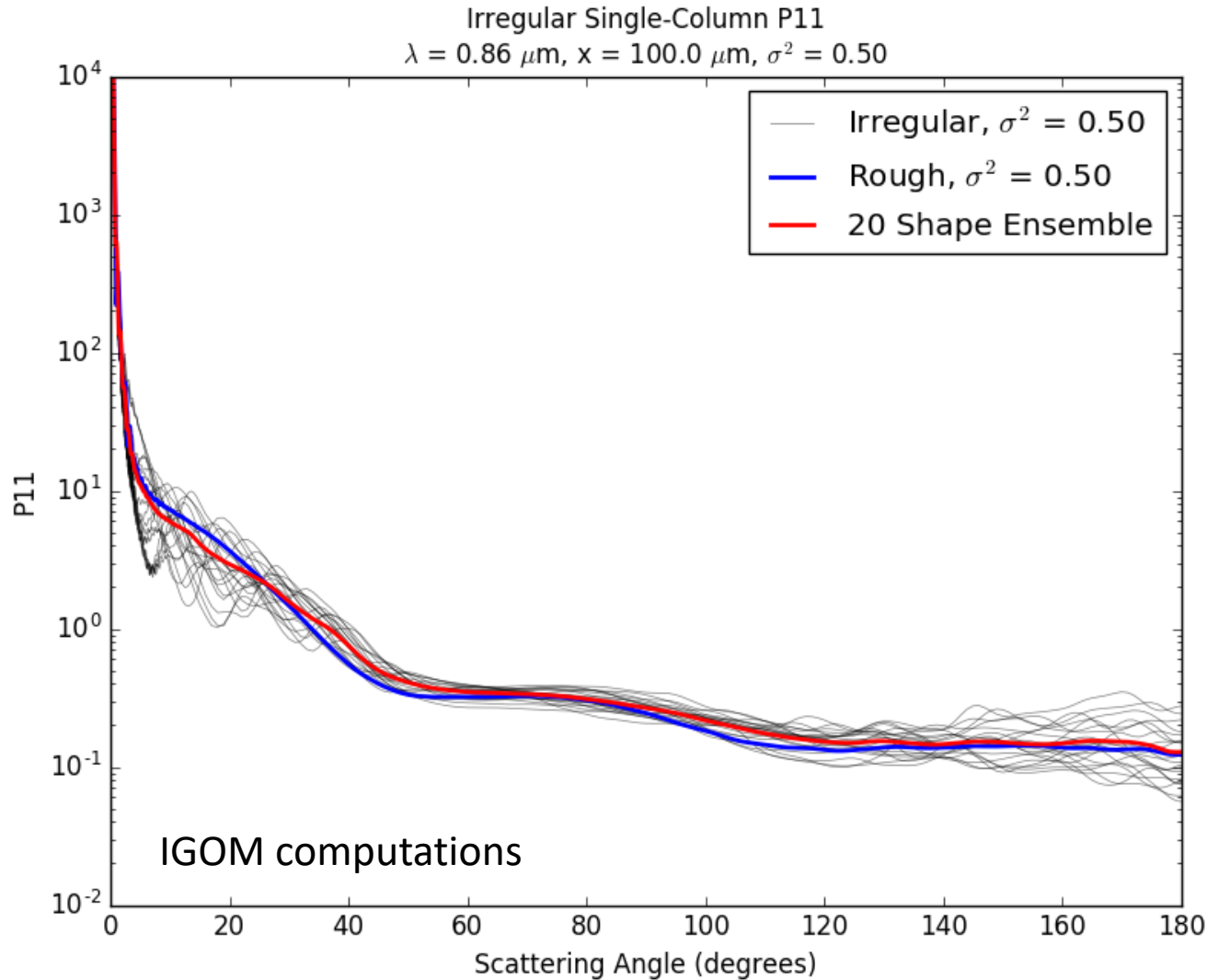# Replacing Roughened Single-Column Particles
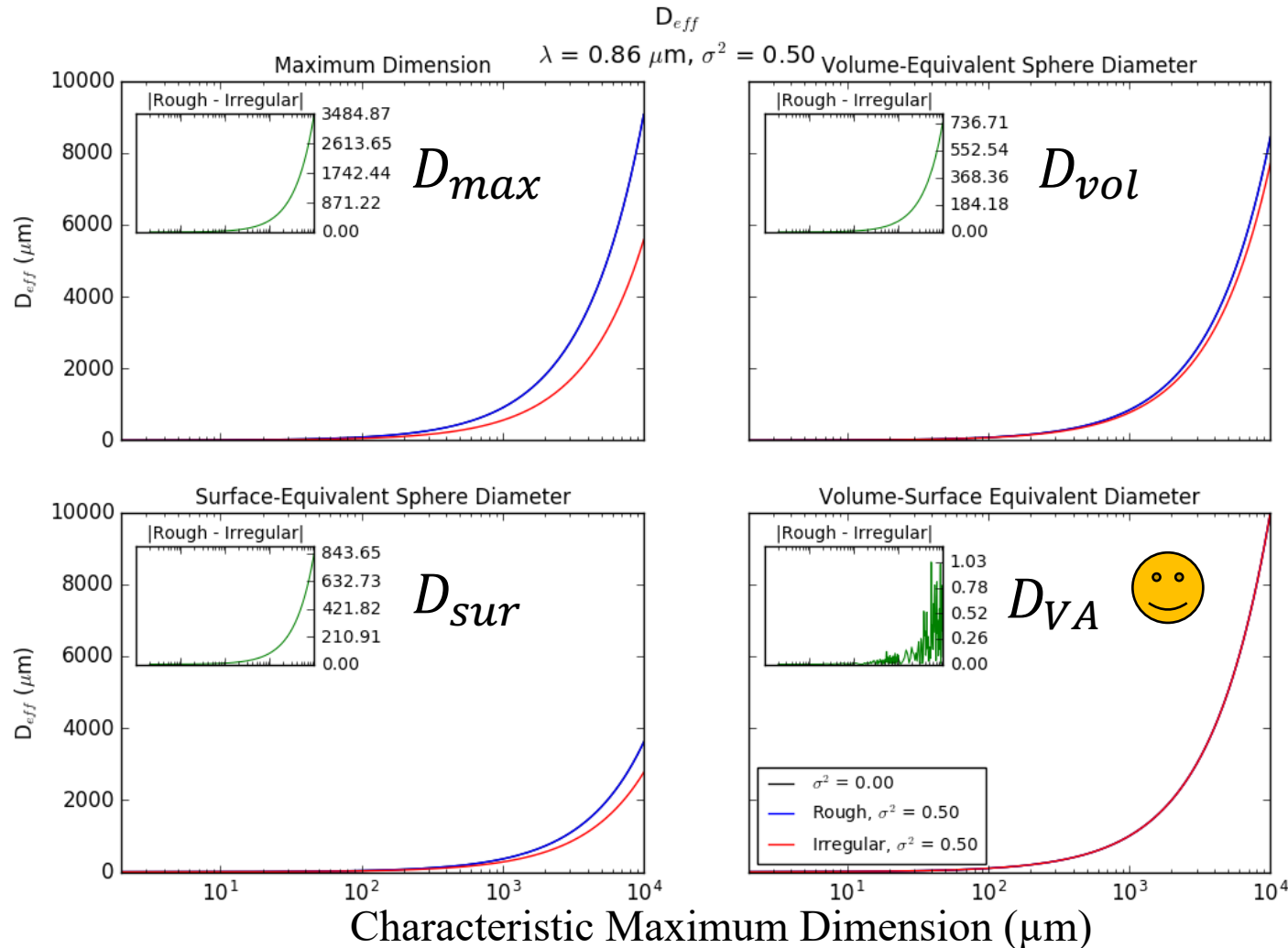
- Volume-Surface Equivalent Diameter (D_{VA}) provides an overall greater consistency of volume and projected area compared to Maximum Dimension.

The Ensemble of 20-Irregular-Shaped Single Column

Irregular Single-Column P11
$\lambda = 0.86\ \mu m,\ x = 100.0\ \mu m,\ \sigma^2 = 0.50$

Legend:
- Irregular, $\sigma^2 = 0.50$
- Rough, $\sigma^2 = 0.50$
- 20 Shape Ensemble

IGOM computations

P11 (y-axis), Scattering Angle (degrees) (x-axis)

**Blue**

Red

Black

Individual irregular shapes

- Phase function of an ensemble of 20 irregular columns essentially match with a single roughened column counterpart based on to the D_{VA} size definition.

Combination of PGOM and IGOM
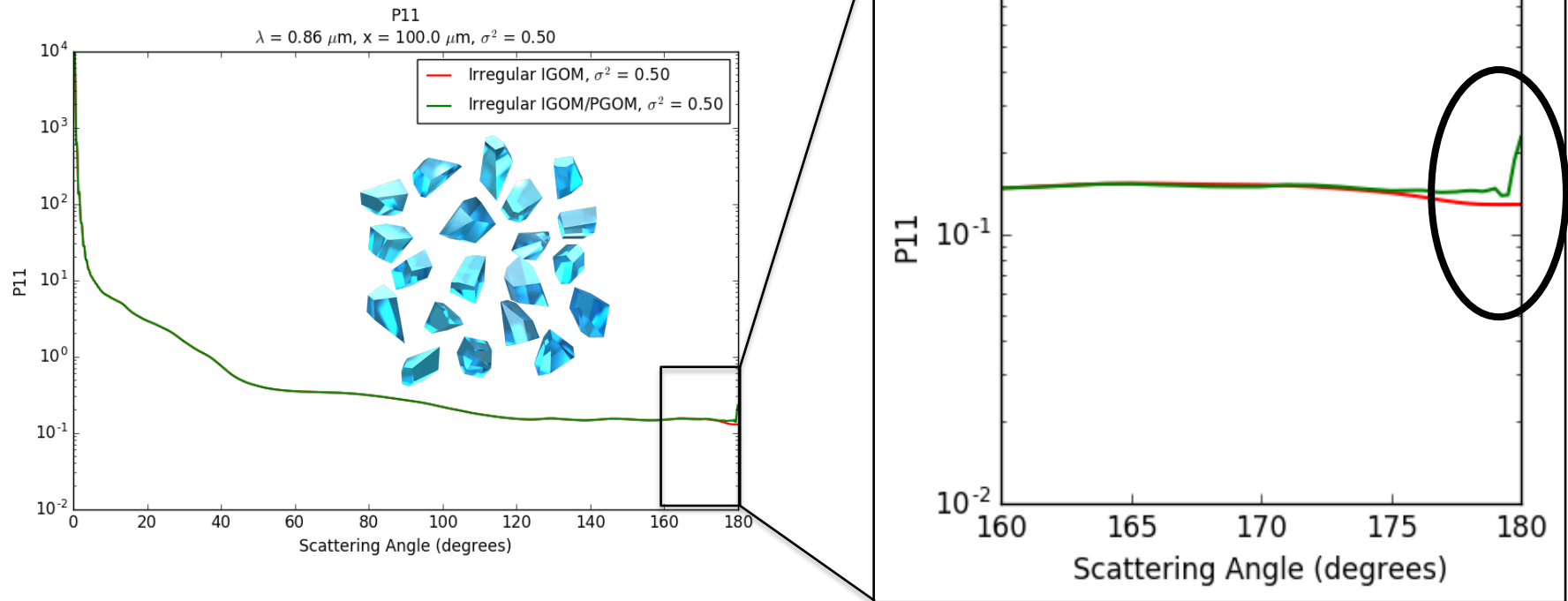
- Phase matrix elements of a single irregular shape:
  - Forward-to-side scattering angles: IGOM computations
  - Near backscattering angles: PGOM computations
- Phase functions show coherent backscattering

→ Enable robust simulations of backscattering signals of active sensors.

Active–Passive Consistency Check
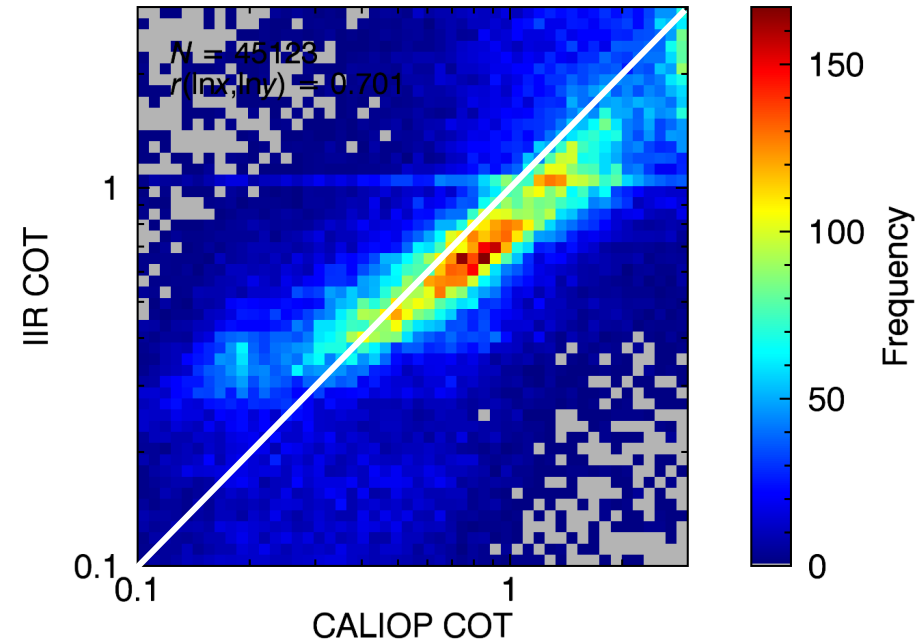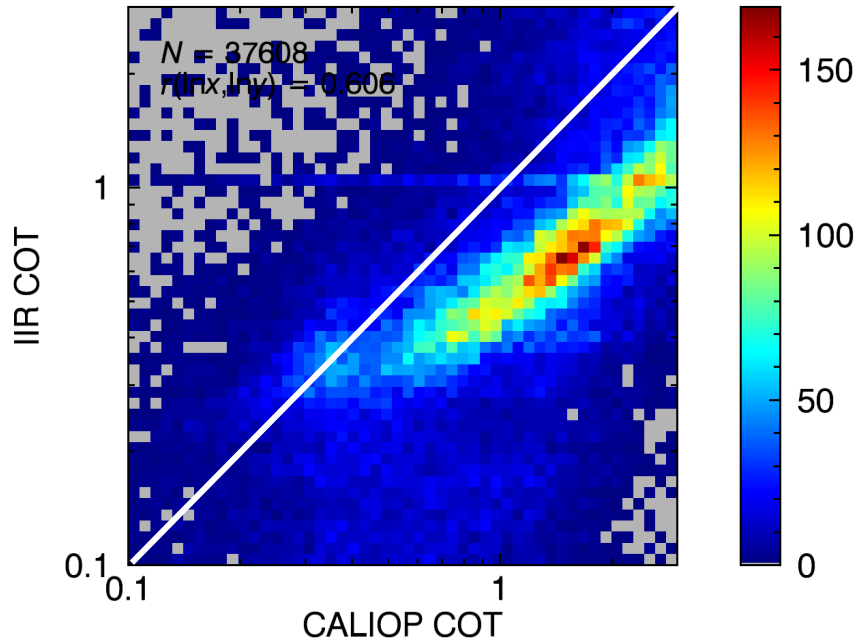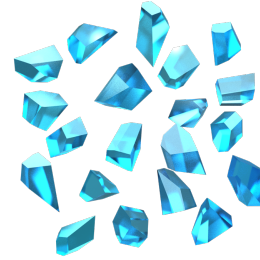
- Future THM shows better consistency between passive and active sensor-based COT retrievals

Summary and Future Plan

- Future THM is in development:
  1. Improved single column representation
  2. Improved backscattering properties
- Near future plans:
  1. Improve backscattering of aggregate particles
  2. Improve small particle scattering property with IITM
  3. Extensive consistency check

Passive Multispectra

Active Sensor

Future THM

Polarimetric Reflectance

Flux Calculations